

VISUAL INSPECTION OF LARGE ELECTRIC GENERATORS

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ABSTRACT

Evaluation of the actual condition of a generator is a challenging task. Inspection has several limitations: necessary to disassemble components, many areas cannot be seen even with the best tools including robots, results are qualitative and highly operator dependent, time consuming. Each of the many tests also has one or more of several limitations: cannot find local discrete weak areas without risk of insulation breakdown, gives averaging results only, insensitive to vital deterioration mechanisms, requires specialized equipment, personnel hazard.

Fortunately, however, the two approaches to generator assessment – inspection and test – are quite complimentary. The combination of a good testing program and thorough inspection by a skilled and trained individual can give a good assessment of almost all common forms of generator deterioration. On generators that are important to system reliability, it is important that both test and inspection be performed, and that neither be neglected nor superficially done.

This paper will cover inspection tools and equipment, as well as approaches to inspection of individual component. Stator components discussed will include, i.e., slot and end portions of the stator winding, core, frame and coolers, high voltage bushings, bearings and seals, instrumentation, and brush holder rigging. Field components will include: field forgings, retaining rings, windings, collectors, collector connections, and fans/compressors. Auxiliaries will also be addressed, i.e., excitation systems, stator liquid cooling systems, hydrogen seal systems, coolers, and lubrication oil systems.

In this paper inspection equipment and procedures will be discussed rather comprehensively but in relatively non-technical terms. The paper will be heavily illustrated to show actual machine conditions on most all of the known deterioration mechanisms on generators. This information should help those responsible for inspecting generators to better understand the strengths and weaknesses of generator inspection procedures, and provide operators of generators a more reliable inspection of the generator. It should also assist owners of generators in implementing better maintenance practices, and thus reduce maintenance costs and extend reliable life of the generator.

INSPECTION GENERAL GUIDELINES

SPECIAL CAUTIONS

Many problems will be immediately obvious to initial glance, and can be seen without entering the generator, i.e., stator winding double failure to ground. Some locations are not easily accessed, i.e., under retaining rings. Some forms of deterioration are very difficult to locate, i.e., stator winding single failure to ground. Some problems are difficult to assess, i.e., stator bar vibration.

It is vital, then, that the inspection be thorough, that proper tools are used, and that conclusions as to winding condition not be lightly or quickly reached.

CHECK-LISTS

Because of the complicated nature of the task, a comprehensive checklist is essential to assuring that important components and areas are not overlooked. Also an organized, consistent approach will make comparison of results of various inspections more meaningful, particularly if subsequent inspections are not performed by the same individual.

Good checklists are available in the literature, or can be custom developed by a qualified individual.

COMMON EVIDENCES OF DETERIORATION

Fortunately many of the prevalent deterioration mechanisms leave tell-tail signs of trouble: dust, dirt, grease, fretting, discoloration, displacement, cracks, foreign objects, deformation, distortion. All of these signs should be kept in mind as the inspection is performed.

However, it must also be kept in mind that the evidence may be subtle and limited, particularly in the early states. Such evidence may be extremely important and may easily be overlooked if proper care is not exercised. Figure 1 is partial discharge burning in an end winding, visible only by careful inspection with a mirror; the bar failed hipot at a low value. Figure 2 appears to be a small amount of “greasing” from minor bar vibration, but more likely is associated with side ripple spring wear deep into the bar insulation.



Figure 1. Arcing Damage from Hipot Test



Figure 2. Dust Deposit on Stator Core Bore from Bar Vibration

TRAINING/EXPERIENCE

Because inspection is inherently difficult and often judgment must be made as to the significance of evidence, it is essential that the inspection be performed by a qualified individual. Training and experience

are important, and on new or more complicated phenomenon, basic generator design understanding will be needed. While inspection itself is challenging enough a task, correctly diagnosing the root cause of more subtle failure mechanisms is even more challenging. The latter may often require the assistance of OEM engineering personnel and/or other individuals particularly qualified on generator design by education and experience.

EQUIPMENT & TOOLS

A cursory inspection can be made with little more than a flashlight. However, when the complete inspection is performed, other hand tools are needed: borescopes (flexible and rigid), background lights, large and small flashlights, various shapes of mirrors, magnifying glass, small hammer, knife, magnet, and still and video cameras and adapters, Figure 3.



Figure 3. Typical Hand Tools for Generator Inspection, Courtesy Enoch Silva, ES Consulting

Some inspection/test operations require special equipment in order to be quantitatively and expeditiously performed: wedge tapping, top ripple spring checks, ElCid test.

Robot equipment is available for inspection with the field in place. Generally, these inspections will not be as good as direct inspection, but still can be valuable and are much less costly and time consuming. Also, risks of disassembly/reassembly damage are greatly reduced. Figure 4 is typical of damage done by field contact with the stator core during generator assembly. Unfortunately, it is not uncommon during robot inspection to find a problem that requires field removal anyway.



Figure 4. Damage from Contact Between Field and Stator Core

TIME INTERVALS

Accessible components should be inspected at every convenient opportunity, but particularly during minor and major outages. Frequency of inspection should also vary based on known problems and on importance of the machine to the system.

In addition, OEM recommendations should be considered in planning of outage schedules, both machine-specific recommendations and general recommendations. In general, OEM's have recommended major inspection with field removed every 5 years. However, the intervals may logically be extended for several varied reasons: satisfactory inspection through use of robots, unit base loaded, low operating hours, particularly reliable performance, cost constraints, unit not of high priority. There are several corresponding reasons for shortening the interval: cyclic loading, known weakness in a component, operating incident, mis-operation, information of concern from the monitoring devices.

EQUIPMENT/COMPONENT ACCESSIBILITY CONSIDERATIONS

WITH FIELD IN PLACE

Fully assembled generators allow little access for inspection. Examination of Figure5 indicates the restricted access even with partial disassembly.

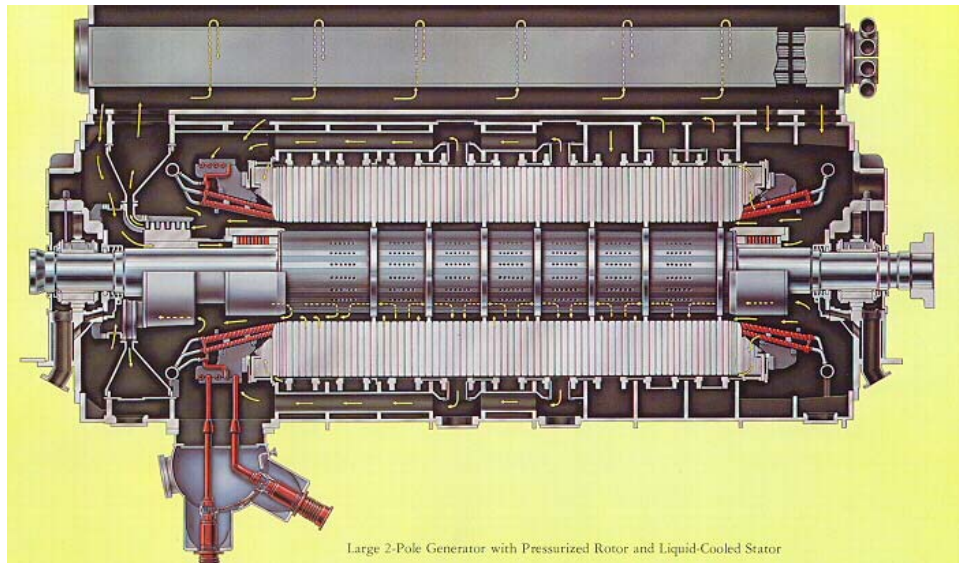


Figure 5. Cross Section of Large Generator (Westinghouse)

Inspection Ports

Manufacturers provide a limited number of ports, primarily for assembly and balance purposes. Generally, little can be observed, although if severe burning has occurred this will ordinarily be readily evident. Removal of covers located behind the core will gain access to portions of the machine, Figure6, and removal of a cooler may allow a small agile person to inspect substantial areas of the core outside diameter and the frame.



Figure 6. Inspection Opening Cut in Frame Behind Stator Core

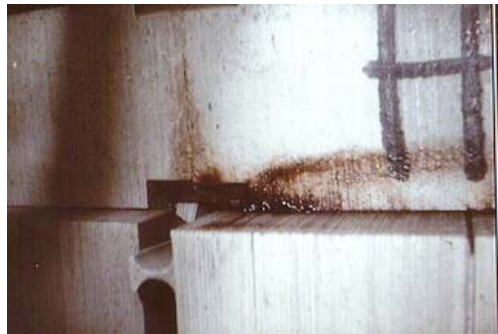
End Shields Off

Removal of the inner and outer top-half end shields will allow important portions of the generator to be inspected, providing the right tools are available. Mirrors, flexible borescope, and miniature video cameras can be placed on extension poles and may give access to the retaining rings, field end wedges, core end iron, and stator end wedges, Figure 7.



Figure 7. View of Stator Connections Using Camera on Extension Pole

Robotic equipment is available that can traverse the entire length and circumference of the airgap, even those with gap baffles. With these robot devices, many additional vital generator parts can be inspected: field wedges, stator bar vibration, Figures 8 & 9, stator and field wedges, stator wedge vibration, stator core, air gap baffles, Figure 10, core ventilation ducts, Figure 11, radial spring ripple height on some wedge designs. These inspections are made with miniature video camera, wedge tapper, and ripple height-measuring attachments.



Figures 8 & 9. Robot Camera View of Stator Bar Vibration and Core



Figure 10. Air Gap Baffle

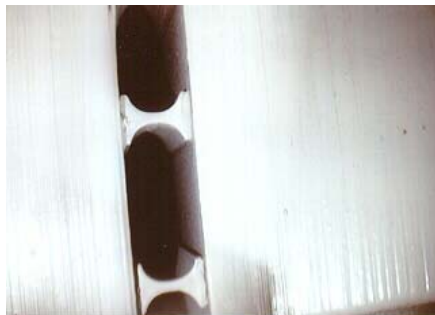


Figure 11. Core Ventilation Ducts

FIELD REMOVED

A “complete” stator and field inspection requires removal of the field. Good access is provided to visible surfaces such as stator end windings, vent ducts via borescope or very small flashlight, and under retaining rings with flexible borescope and mirrors, Figures 12 & 13.



Figures 12 & 13. Field Winding Inspection with Mirror and Direct View

Examination of stator bars is greatly improved, and this will allow better determination of the critical mechanisms of slot discharge and insulation mechanical wear due to vibration. Disassembly of stator wedges is also facilitated.

Even with the field removed, however, there remain inaccessible locations: most internal components of the field, most of the core, stator slots below wedges.

Removal of retaining rings, and some field coil blocking, will allow the entire field end winding to be inspected for distortion, cracks, and ventilation problems. Examination of the full surface of the retaining rings is also permitted.

DUTIES ON COMPONENTS (SPECIAL CONSIDERATIONS)

MECHANICAL

Because most failure mechanisms are mechanical in nature, increased attention should be given components on which mechanical duties are particularly high. Important components on stators would include: stator bars, wedges, bar connections, end-winding support, core laminations. On fields: field

copper turns, coil and collector connections, forging, retaining rings, wedges, collectors, journals. On the frame: core key bars, coolers, welds and other attachments, bearings, hydrogen seals.

ELECTRICAL

Electrical stresses are a concern on both stator and field windings. In stator slots, electrical discharge (vibration sparking) can eat away the bar insulation in areas very hard to inspect. In the stator end winding, partial discharge deposits may be found where bars and connections in different phases are in close proximity.

Most large fields contain extensive creepage surfaces, which can become contaminated. Field turn insulation and slot liners can crack or migrate. Collectors operate in a contaminated atmosphere (carbon dust) which will deteriorate the creepage paths.

LIQUID LEAKS

Three normal sources of leaks are found on large generators: bearing oil, water from coolers, and water from stator bars on direct cooled windings. Unfortunately, leaks from each of these sources are common. In widely differing ways, leaks of any type can have serious negative impact on generator reliability and durability.

Lubrication oil can degrade some types of insulating materials, reduce friction coefficients on stator bar slot restraint systems, and combine with dusts to form heavy deposits which can restrict or plug ventilation circuits, fill ventilation passages, and inhibit heat transfer. Water leaks from coolers can facilitate stress corrosion cracking of retaining rings, degrade electrical creepage paths with or without lead carbonate formation, deposit contaminants on stator end windings. Minute stator bar strand header water leaks can irreversibly damage stator bar groundwall insulation, and can lead to stator winding hipot or service failure. Large stator winding water leaks can be associated with loss of water flow to stator bars (with differential fracture of bars), and interruption of stator winding current flow (with severe arc damage).

Each of these problems can result in long forced outage with major repairs.

STATOR INSPECTION PROCEDURES

SLOT PORTION OF WINDING

Slot electromagnetic forces are high and deterioration is common and can be severe. The slot portion of the stator winding is probably the most critical and difficult area of a generator to properly inspect. Most of the important areas of interest are enclosed behind the wedges and the core iron. Proper inspection becomes tedious, but if proper tools are on hand and if the operator is patient, persistent and perceptive, a good inspection can be accomplished. Considering various deterioration mechanisms and locations:

Slot Wedges & Bar Vibration

Partial or complete looseness of individual wedges can be detected by tapping either manually with a small hammer or by mechanized means. Also, commonly there will be dust or “grease” generated by the fretting actions, and these deposits will be easily seen, although not easily assessed. Where dust and/or grease are present, it is important to distinguish between simple wedge vibration, which may not be a serious concern, and bar vibration, which is always a deep concern. Loose wedges may simply vibrate small amounts and generator significant amounts of dust without causing measurable damage to the wedge or the iron, Figure14.



Figure 14. Dust Generated by Vibrating Wedges

But loose wedges may also allow bar vibration, may wear into the core iron, and may allow filler migration. The degree of winding deterioration can not easily be assessed by observing the amount of dust or grease. If deposits are widespread and heavy, it is certain that bar vibration is occurring. However, local and relatively small deposits of dust or grease may also be associated with severe bar vibration damage, Figure 2.



Figure 15. Severe "Greasing" Due to Bar Vibration at Ends of Core

Bar vibration occurring only at the ends of the core, without bar vibration occurring towards the center of the core, Figure 15, is almost certainly due to the bars being held off the bottom of the slot. Wear can occur with very small clearance, perhaps less than 5 mils. Clearance less than about 30 mils can not be seen directly or with a borescope, nor measured by feeler gauge. However, these small clearances can be detected by bar jacking at the end of the slot. Figure 16 shows this process using a standard bar jack and a core-mounted dial indicator.

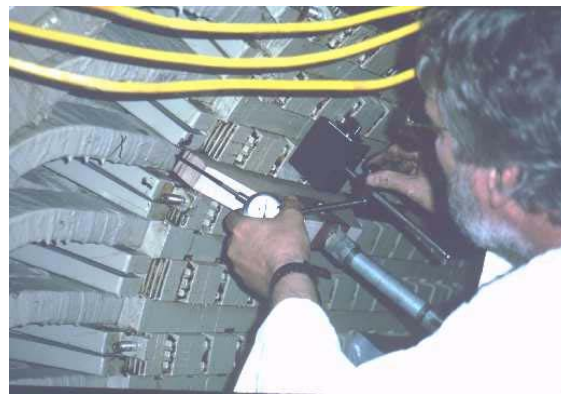


Figure 16. Bar Jacking Process for Assessing Slot Clearance

Stator Bar Insulation

Access to stator bars is limited and only available at the core ends and through ventilation ducts. In the ducts, side packing and ripple springs will limit access to the bars. Care should be taken to examine both sides of each bar as it exits the slot, where access for inspection is good. In the core area, a borescope sufficiently small in diameter to enter radial ventilation ducts may help in evaluating: groundwall insulation partial discharge pitting and mechanical wear, quantity of dust or grease buildup, puffing or bulging of insulation, severe insulation cracks or migration, filler migration, and large radial clearances. Figures 17 & 18.



Figures 17 & 18. Inspection for Stator Bar Slot Vibration by Borescope and Flashlight

It should be noted that observations through a borescope are magnified and distorted; the operator must clearly recognize and allow for this distortion. In some cores with wider ($>3/16$ ") ventilation ducts, a very small flashlight will also allow direct, undistorted observations near the top of the slot, Figure 18. Removal of wedges and fillers may also assist in assessing suspected deterioration.

END WINDINGS AND CONNECTIONS

The stator end windings are more accessible than the slots. The forces are lower, but the restraining systems are also less effective. In addition, vulnerability to foreign object entrapment and wear is high. Thus inspection of end windings and connections also requires that the operator be patient, persistent and perceptive in examining all areas. Considering various deterioration mechanisms and locations:

Vibration

May be observed on all components and at all locations, and usually will be evidenced by dust or grease deposits, Figures 19 & 20. Unless trivial, indications of vibration are always a cause for concern. Blocks, rings and ties should, therefore, be inspected carefully and checked for looseness by tapping and/or small mechanical force.



Figure 19. Dust Generation from Connection Ring Vibration

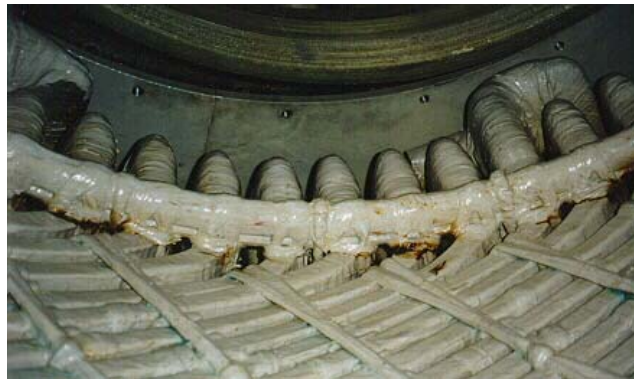


Figure 20. Stator Bar End Winding Vibration

Partial discharge Activity

Partial discharge can result in several conditions that are detectable by thorough inspection. The most serious of the operating conditions is the whitish deposit shown in Figures 21a & 21b. This damage results from intense partial discharge and may cut into the insulation. (Cases have been reported where the depth of damage is believed to exceed 20% of the insulation wall.) In hydrogen cooled generators, partial discharge may deposit a brown-sugar appearing solid.



Figure 21a. Partial discharge at Line-to-Line Phase Break in Stator End Winding

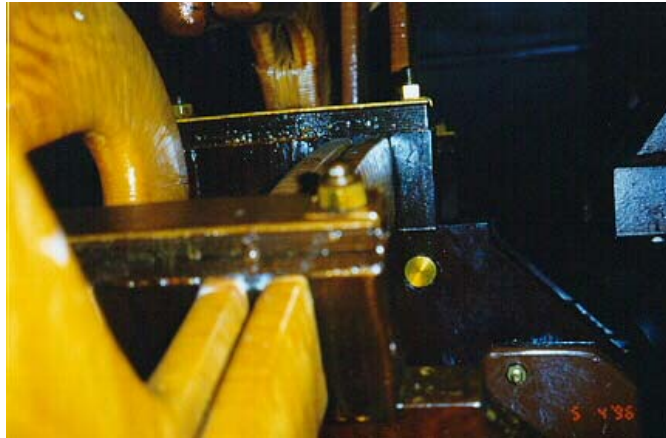


Figure 21b. Partial discharge Between Two Line Voltage Connection Rings

Both air-cooled and hydrogen-cooled generators have formed brown or black semi-liquid deposits. Figure 22. These materials are suspected of being a product formed from bearing oil vapor in the presence of a high voltage partial discharge field. If the partial discharge activity is not cutting into the insulation, cleaning may be the only action required.



Figure 22. Deposit Resulting from Partial discharge Field Acting on Lubrication Oil Vapor

High voltage test may also damage insulation through severe arcing. Figure 23 shows damage probably resulting from factory hipot.



Figure 23. Arc Damage from Stator Hipot

All indications of partial discharge activity should be carefully examined for determination of necessary corrective action.

Short Circuit Damage

If the generator has been subjected to a short circuit or mis-synchronizing incident, the winding will have experienced mechanical forces which can be very high, in the order of 100 times maximum normal operational forces. Check for broken ties and bar displacements, Figure 24, bar insulation hairline cracks, Figure 25, and cracks in the blocking (beyond the normal hairline cracks associated with differential expansions).



Figure 24. Broken Ties and Bar Displacement Due to Short Circuit Forces

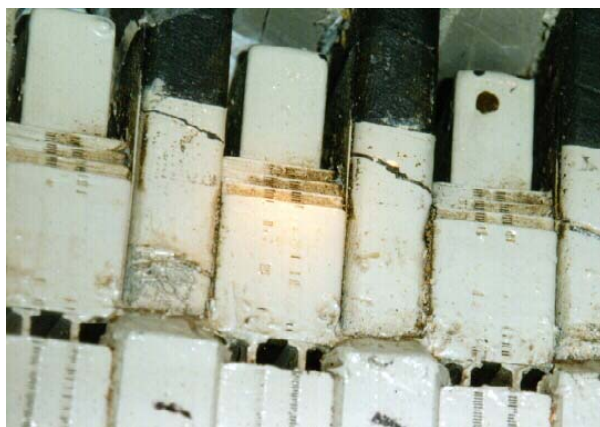


Figure 25. Severe Cracks from Short Circuit Forces

Foreign Objects

Foreign objects may be located anywhere in the matrices of the end winding and connections. Often an object may be very difficult to detect, unless generating tell-tail dust. If foreign object intrusion is suspected, inspection should be particularly thorough.

Tape Migration

Many large asphalt windings and a very few early thermoset windings have experienced this problem, usually on the top bars and at the collector end of the winding. The classic manifestation of tape migration is the “girth crack”, or separation of the surface layer of tape at the end of the slot, Figure 26 and Figure 27.

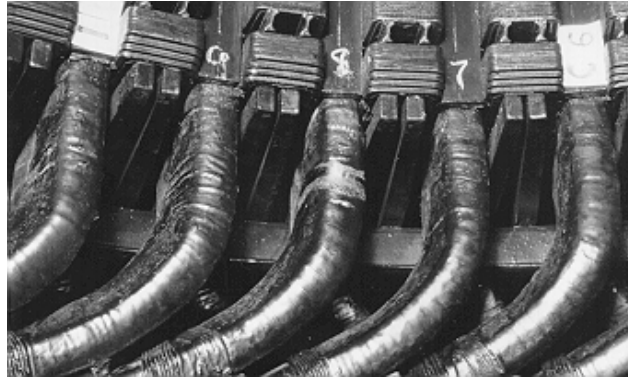


Figure 26. Armature Bar Girth Cracks Resulting from Tape Migration



Figure 27. Close View of 1-1/4" Wide Girth Crack

Two inspection information sources relate to amount of damage done to a specific bar:

- 1) total amount of tape migration, and
- 2) physical appearance of the bar in the area of the separation.

Assessing the total amount of migration is difficult. The separations occur in the area from about 4" inside the core to 12" beyond the end of the core, but most commonly in the 6" area of the bar just outside the core. If the girth crack appears in the end winding and the winding has not ever been painted, the width of the separation is the amount of the migration. If the winding has been painted, one must sum the amounts of migration observed between each application of paint. Since such records are rarely kept, determination of total amount of migration generally is not possible. This is unfortunate because amount of deterioration closely correlates with total amount of migration. Significant deterioration usually has not occurred with migration of less than 1/2", and may not be serious with total migration of 1".

Evaluating the physical appearance of the bar is often equally difficult. If a deep crack exists, the bar can be regarded as unusable. More commonly the bar may appear to be normal except for the surface separation. Any bar showing evidence of insulation migration should be examined by hand pressure for signs of sponginess or indications of voids. (Asphalt insulation is rigid at room temperature; if the surface of a suspect bar is raised to about 40C by heat lamp, examination for sponginess will be easier.)

Because of the difficulty and uncertainty of inspection of asphalt windings for tape migration, hipot is particularly important on these machines. It should be kept in mind, however, that if the winding is clean and dry, a defective bar may fail without warning and require that the bar be replaced. Fortunately, tape migration is predominately in top bars, thus allowing relatively easy replacement.

CORE

Most core deficiencies can be observed from the core surfaces, and a careful inspection (combined where appropriate with core flux test) will give a good assessment of core condition. Considering the various deterioration mechanisms and locations:

Contamination

Contamination may be heavy on the core inside diameter and in ventilation ducts. Sources include ambient dirt, rain, bar vibration wear, wedge vibration, bearing oil leaks, core lamination vibration, Figure 28. Examination should determine source and nature of the contamination in order to facilitate corrective actions.



Figure 28. Heavily Contaminated Stator Core

Minor Mechanical Damage

Minor mechanical damage may range from a small knife or chisel cut to punchings bent during rewedging or field removal. Generally confined to the accessible inside diameter areas of the core, but may not be detected unless inspection is thorough.

Minor Overheating or Burning

Mechanical damage may result in shorting of only a few adjacent punchings. The fault will appear as a small, localized solid-metal surface, or alternatively, small areas of scorched lamination paint. Figures 29 & 30. These conditions can be serious, and may be overlooked if inspection is not thorough.



Severe Mechanical Damage

Severe mechanical damage can be caused, for example, by foreign objects, by careless wedging, or field removal. Figure 4. It usually will be widespread, easily observed and very serious. All damaged spots must be located and identified for corrective actions.

Looseness

Core looseness usually will occur at the inside diameter near the ends of the core. However, it is possible for looseness to be general and/or exist on the core outside diameter. If looseness is suspected, degree of looseness can be evaluated by carefully inserting a knife blade between punchings, Figure 31. Looseness may be accompanied by dust generation, punching and spacer movement, or small pieces of punchings flaking or cracking off.



Figure 31. Use of Knife to Check for Core Looseness

Cracked Laminations

Cracking of laminations usually occurs at the ends of the core. Pieces will be missing and may have worn into stator bar insulation. May be accompanied by general or local core looseness.

Displacements

Individual punchings, groups of punchings, or outside or inside space block assemblies may move tangentially or radially. Care must be taken to distinguish between original stacking errors, which may be up to about 15 mils, and actual migration. Since punching displacement can result in armature winding failure, inspection should be carefully performed.

Damage from Lamination Insulation Failure

Lamination insulation failure damage may be evidenced by general or localized surface overheating (bluing) or burning of paint, and in extreme case, melted iron, Figure 32. It may also involve the core outside diameter and/or support structure. This is always a serious condition which must be identified and corrected (probably by re-stacking core).

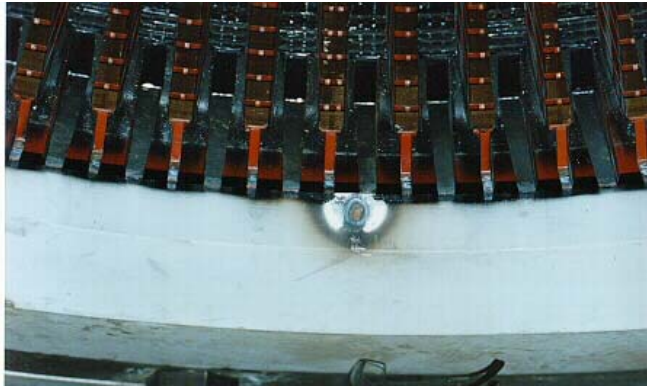


Figure 32. Severe Core Overheating Requiring Re-stacking

Core Damage Due to Over-fluxing

Burning will focus on the ends of the core and on the keybars behind the core iron. Assessment of extent of damage may be difficult, particularly since burning may occur within the core back-iron. An incident may appear to involve only small amounts of burning and look as if minor. However, more significant damage may have occurred deep in the core and on the keybars, Figure 33. In the worst case, burning will be severe at core ends (with holes melted in the teeth), and with large burn areas behind the core between core and keybars, Figure 34. The latter condition will usually be accompanied by stator winding failure. In all cases, whether appearing minor or severe, core over-fluxing damage is a serious concern and must be thoroughly investigated.



Figure 33. Keybar Burning Due to Over-flux Incident



Figure 34. Melted Keybar and Tooth Areas Due to Over-flux Incident

FRAME AND COOLERS

Frames ordinarily are not the cause of generator problems. However, there are issues which should be kept in mind and the frame inspected accordingly.

Dirt and Foreign Material

Because of the complexity of the structure, there are many areas for accumulation of contaminants, Figure 35. Because these materials can be carried by the high velocity ventilation gases, all accessible portions of the frame should be examined.



Figure 35. Oil Accumulation in Stator Frame

Vibration

Accessible attachment points should be checked for evidence of fretting, such as dust generation. Vulnerable locations include keybars, section plates, and cooler supports, Figure 36.



Figure 36. Wear Products from Vibration of Cooler Components

Cracks and Distortion

In the event of malfunction of the generator, or known weakness of design, complete examination should be made of the wrapper, core attachment points, and other components of the frame. This inspection is particularly important on hydrogen cooled generators, Figure 37.



Figure 37. Inspection for Cracks in Generator Frame Structure

FITS & HARDWARE

Throughout the entire generator, all locks, bolts and other attachments should be examined for looseness, displacement, or fretting, Figures 38 & 39.



Figures 38 & 39. Fretting Winding Support and Field Balance Weight Locks

HIGH VOLTAGE BUSHINGS AND STAND-OFF INSULATORS

There are numerous deterioration mechanisms and locations which must be evaluated:

Contamination - Standoff insulator and high voltage bushing gas passages must be open and free of blockage. If a large quantity of lubrication oil has entered the machine, check that gas cooled bushings do not contain oil internally.

Fretting - Check the bond between the porcelain and metallic flange of standoff insulators and high voltage bushings for evidence of cracking, looseness or fretting, Figure 40. Also check that all bolted connections are tight and properly locked.



Figure 40. Standoff Insulator with Unbonded Flange

In some generator designs, direct access can not be made to the junction between porcelain and flange, but products of wear and vibration may flow out of the ventilation pipe in the form of blackish deposit, Figure 41.



Figure 41. Flow of Vibration Products from Loose Standoff Bushing Flange

Mechanical Damage - Inspect for chipped or cracked porcelain on bushings and standoff insulators.

Electrical - Check for tracking or other indications of electrical distress.

Overheating - Most electrical connections are brazed and should not be subject to failure. Some are bolted and accessible, Figure 42. Some are covered with several layers of insulation and are thus difficult or impossible to inspect, Figure 43. However, surface conditions should be checked for signs of over-temperature which may suggest a failing electrical connection.



Figures 42 & 43. Bolted Accessible Isophase Electrical Connection and Bolted Insulated High Voltage Bushing Connection

BEARINGS AND SEALS

Primary areas of concern are mechanical deterioration of the journal contact surfaces and loss of insulation integrity. Considering these areas:

Bearings - Usually will have some deterioration due to normal wear and minor amounts of foreign material passage, but damage may occasionally be serious, Figures 44 & 45.



Figures 44 & 45. Bearing Scored by Foreign Material

If insulation is defective and current has been flowing, surfaces will tend to appear etched. Babbitt bond to the forging may also be broken, and this condition must be evaluated. Assessment of extend of damage to the babbitt is usually apparent, but determining corrective actions may be judgmental.

Seal Rings - Check for weak springs, seal ring friction or hang-up, damage to all contact surfaces.

Insulation - Check face and bolt insulation for missing pieces, cracks, contamination build-up, debonding, loose or missing screws, Figure 46.

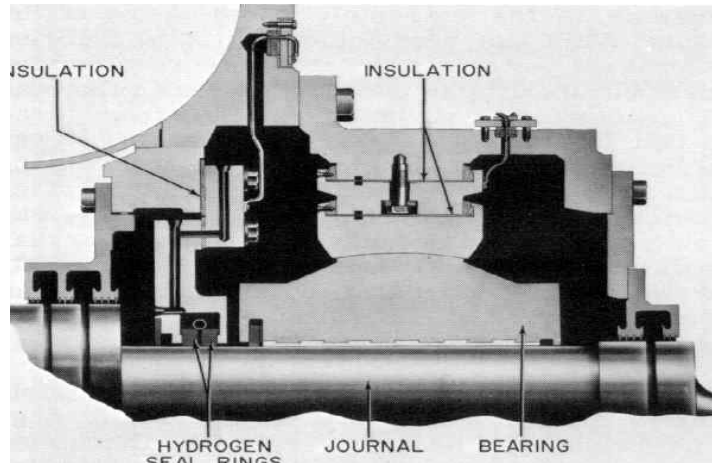


Figure 46. Hydrogen Seal/Bearing Assembly with Insulation Components

INSTRUMENTATION

Temperature sensors and leads are vulnerable to mechanical damage by personnel entering and working in generator, Figure 47. All components should be checked accordingly. Also, mechanical attachments should be checked for loose or inadequately locked hardware.



Figure 47. RTD Damaged by Careless Personnel

BRUSH HOLDER RIGGING

Rigging should be examined for contamination, burning, poor connections, cracked metallic or insulating components, loose hardware, weak or broken springs, and burning of boxes. Figure 48.



Figure 48. Collected Opened for Inspection

FIELD

WINDING

Check field winding so far as accessible for coil displacements or deformation, turn displacements, contamination build-up, turn and slot insulation displacement and cracks, shifted or missing blocking and baffling, and arcing or burning between conductors (coils, turns, leads) and ground.

If retaining rings are not removed, inspection of end portion of the winding is difficult. On some designs, limited access can be obtained directly, Figures 13 & 49, or by use of mirrors, Figure 12.



Figure 49. Inspection of Underside of Coils of Assembled Field

Most designs will give some access to borescope inspection. This inspection is tedious and time-consuming. Interpreting the borescope views is challenging because of distortion, uncertainties of location, and limitations of perspective. With retaining rings and insulation removed, access is good and inspection can be quite complete, Figure 50.



Figure 50. Field Winding Turn Distortion Accessible After Retaining Ring Removal

On direct ventilated fields, inspection can be made through the ventilation holes in the wedges on the body portion of the field, Figure 51.

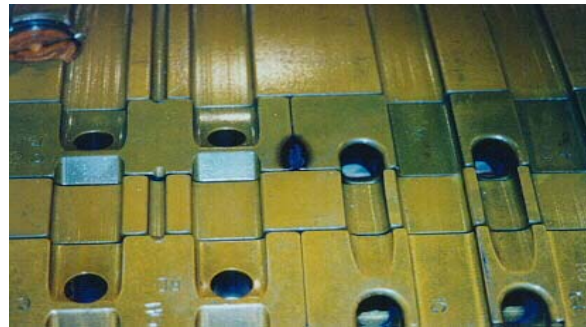


Figure 51. Field Ventilation Holes, Direct Cooled

Valuable information may be found relative to copper dust generation, Figure 52, foreign material contamination build-up, and displacement of turn insulation and/or copper.



Figure 52. Copper Dust Generation Site on Field Turn

COLLECTOR

Most areas of interest are accessible. The collectors should be carefully inspected for depth and uniformity of surface wear, surface etching and burning, insulation contamination and cracks, arcing or burning of insulation and metallic parts, mechanical damage. Figure 53.

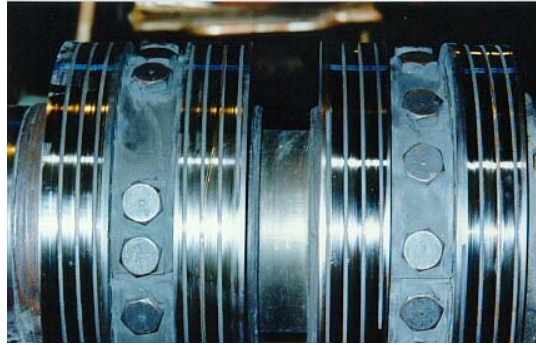


Figure 53. Collector in Good Condition Except for Heavy and Deep Wear

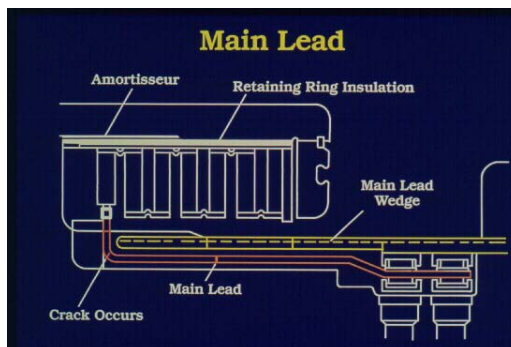
COLLECTOR CONNECTIONS

Access to the connections is limited, but visible component should be checked for cracks, deformation, overheating or burning, and mechanical damage. Particular care should be focused on borescope check of accessible connections under the retaining ring, Figure 54.



Figure 54. Distorted Borescope View of Crack in Main Lead Under Retaining Ring

With retaining ring removed, access is improved, Figures 55 & 56.



Figures 55 & 56. Schematic of Main Lead and View of Cracked Main Lead

FORGING

Many portions of the field forging are accessible, and inspection should be thorough. General concerns are: local or general overheating, cracking, rust, fretting, contamination, mechanical damage. Specifically:

Local Overheating - Most commonly is caused by negative sequence currents associated with asynchronous conditions or significant unbalance of armature phase currents. Evidence will be seen at the ends of the winding slots and at the ends of pole-face cross-slots. May range from slight discoloration to actual burn, arc damage and local cracking, Figure 57.

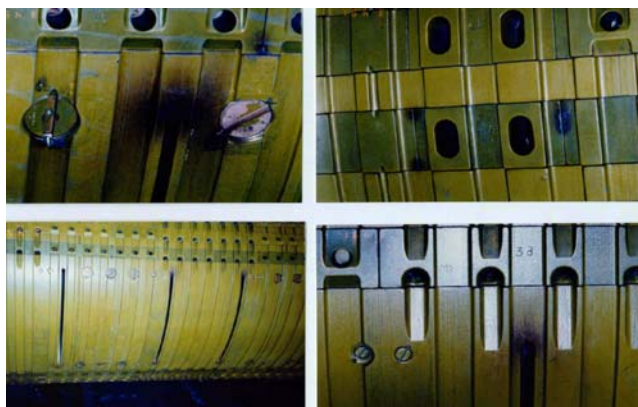


Figure 57. Various Forms of Evidence of Forging and Wedge Overheating

General Overheating - Usually will be accompanied by stator overheating, Figures 58 & 59. Paint may be blistered and peeling.



Figures 58 & 59. Blistered Paint and Extended Armature Bars from Severe Over-temperature Incident

Forging Cracks - May be visible to the naked eye. Most likely to occur on teeth at the ends of the slots, but circumferential cracks have been found on the pole face at the top of the slot at the body centerline. Inspection should be accompanied by NDE, as this is a sensitive evaluator.

Contamination and Rust - cursory inspection will ordinarily assess these problems, but rust may be found in localized, less accessible areas. If machine is heavily contaminated, large build-up of contaminants may be centrifuged onto entrapment surfaces. Figure 60 & 61.



Figure 60. Heavily Contaminated and Rusted Field



Figure 61. Rust Accumulation on Centering Ring and Retaining Ring

Mechanical Damage - Should be easily observed. Because of the high surface rotational speed, 300 to 400 mph, any substantial object can cause significant impact damage to the forging and other rotating components.

Fretting - Likely only to occur between components where shrink fit to the forging has been lost: fans, centering and retaining rings, balance rings, Figure 39.

WEDGES

Wedges are subject to several important problems:

Cracking and Deformation - May be visible to naked eye if severe, although cracks more commonly will be on the dovetails and not accessible without wedge disassembly. Deformation may occur, particularly on non-ferrous materials. Any radially outward displacement needs to be found and may be detectable only by measurement.

Axial Displacement - Easily detected by examining lock area and gap between wedges and retaining rings. This is a fairly common phenomenon on certain field designs, particularly if wedges are not locked securely, Figure 62.



Figure 62. Field Wedge with Poor Lock and Axial Movement

Burning and Arcing - Negative sequence currents will cause current flow that may burn the wedges. Burning will normally be found at the ends of wedges, particularly near the end of the rotor body, Figures 51 & 63. Burning may also be in the dovetail area, and also between the end wedges and retaining rings, if wedges have contacted non-body-mounted retaining rings.



Figure 63. Burning of Removed Field Slot Wedge

RETAINING RINGS

NDE testing will be the primary assessment of retaining ring condition. However, careful visual inspection is essential to record gross evidence of concerns: visible cracks, fretting, movement on shirk fit, etching, burning, rust (on magnetic rings), and mechanical damage, Figure 64.



Figure 64. Retaining Ring with Minor Pitting Detected

Visual inspection should be thorough, using good lighting and magnifying glass as necessary.

FANS/COMPRESSORS

Design variations are extensive, and inspection procedures will vary widely with design. In general, during inspection search for: cracks, contamination, rust, mechanical damage, missing parts, deficient component locks, fretting, displacements, bent components, and deformation.

As in the case of retaining rings, NDE is necessary to reliably validate condition of these rotating components.

EXCITATION EQUIPMENT AND AUXILIARIES

EXCITATION SYSTEMS

Brushless exciters should be inspected for contamination, mechanical damage and other forms of deterioration, Figures 65 & 66.



Figures 65 & 66. Contaminated Shaft Driven Brushless Exciter Rotor and Stator

Static excitation components should also be inspected for mechanical deterioration and contamination, Figures 67 & 68.



Figures 67 & 68. Contaminated Static Excitation Components

The early-design DC exciters are particularly subject to contamination, component wear and mechanical damage; these components should be inspected accordingly, Figures 69 & 70.



Figures 69 & 70. Contaminated DC Exciter Armature and Field

STATOR COOLING WATER (AND OIL) EXTERNAL SYSTEM

Numerous varied components make up the stator cooling water system external to the generator: cooling water piping, flanges, electrical controls, valves and regulators, pressure sensor lines, coolers, pumps, motors, and storage tank, Figure 71.



Figure 71. Typical Large External Pumping Unit for Liquid Cooled Generator (Westinghouse)

Deterioration mechanisms vary widely between components, and a proper inspection will require use of several skills. Listing some of the numerous deterioration mechanisms and locations which must be evaluated on the individual component:

Piping and Flanges - Leaks, contamination, loose supports, mechanical damage.

Electrical Controls - Malfunction, overheating components, mechanical damage, poor connections.

Valves, Lines and Regulators - Smooth operation, air or hydraulic leaks, wear, mechanical damage.

Coolers - Internal and external leaks, internal contamination, thin or plugging tubes.

Pumps and Motors - Flexible coupling wear and alignment, water leaks, overheating, mechanical damage, output pressure, vibration.

Storage Tank - Internal contamination, leaks, sight glass visibility, spray lines clear.

HYDROGEN SEAL OIL EXTERNAL SYSTEM

Problems and wear mechanisms are similar to the Stator Water system, excepting typically there will be no cooler, Figure 72. Guideline in the previous section on water cooling systems can be followed.

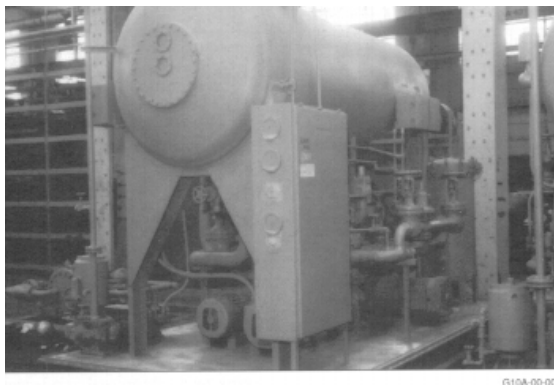


Figure 72. Typical Hydrogen Seal Oil Pumping Unit (General Electric)

HYDROGEN/AIR COOLERS

Should be inspected for evidence of tube, tube-sheet leaks (discoloration, chemical deposits, rust), tube plugging, Figure 73. If tube vibration is occurring, fretting products should be visible. Fins should be checked for spalling, breakage, and bends.



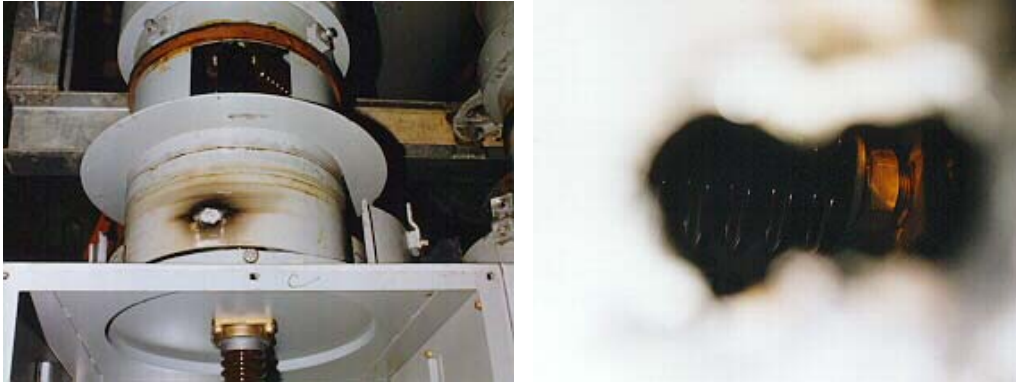
Figure 73. Cooler Tube Sheet with Cover Removed

LUBRICATION OIL

Generally lubrication oil will be supplied from the turbine system. Inspection items would be similar to the information on stator water and oil external systems. In addition to the condition of the mechanical and electrical equipment, the lubrication oil itself should be checked for particle count, neut number, and other properties.

ISO-PHASE

All internal & external accessible components should be inspected for: local and general overheating, local burning or overheating of electrical connection joints (between isophase sections and on ground straps), failed insulators, Figures 74 & 75, cracking of ground straps or other components and connections, contamination, loose or fretting connections, Figure 42, mechanical damage. If forced cooling is used, the blower/cooler system should be checked for malfunction or incipient difficulties.



Figures 74 & 75. Hole Burned in Isophase by Standoff Insulator Failure, External View and View of Insulator Through Hole in Cover.

Figure 76 provides an isometric view of an isophase system and indicates the complexity and large number of components.

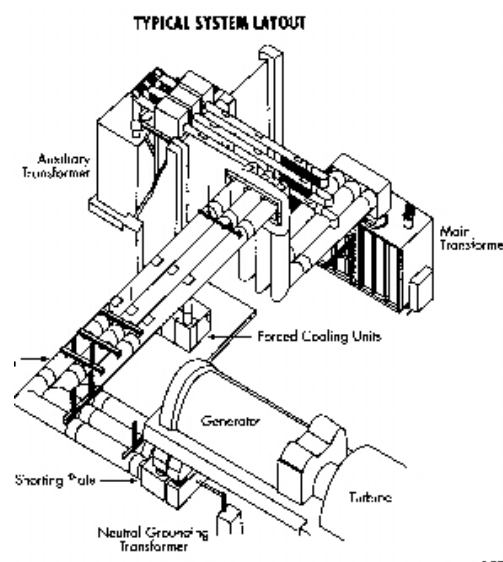


Figure 76. Isometric View of Isophase System